ESTIMATION OF AMBIENT RADIATION TEMPERATURE FOR EMISSIVITY-CORRECTED THERMOGRAPHY

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Abstract - **A non-contact method for the measurement of emissivity, and emissivity-corrected temperatures has been developed, where the ambient radiation-temperature is changed in a discontinuous way. When the ambient radiation-temperature is changed quickly, so that the surface temperature of the object can be assumed to be unchanged, the radiometer output before, and immediately after that change can be expressed as two simultaneous equations. The temperature and emissivity of the surface can be derived by solving these equations when the ambient radiation-temperatures are known. In previous studies, one or two hoods were used to provide the ambient radiation-temperature. However, there was a problem in controlling the ambient radiation-temperature. A new method is introduced where two reference plates coated with paints of different emissivities are placed in the field of view of the infrared camera. Eight simultaneous equations were derived from regions of the plates, and the ambient radiation-temperatures before and after the change were obtained by solving these equations. The validity of this method was confirmed by experiment. This method will eliminate the need to use hoods as in the previous report, and will simplify the equipment needed.**

Keywords - **Thermography, emissivity-corrected thermography, ambient radiation temperature**

I. INTRODUCTION

A non-contact method for the measurement of emissivity, and emissivity-corrected surface temperature, where the ambient radiation-temperature is changed in a discontinuous way, was proposed by one of the present authors [1]. The discontinuous change of the ambient radiation-temperature was achieved by quickly interchanging two hoods at different temperatures [1–3]. However, the mechanical switching of two hoods was unacceptably slow, and introduced errors in the measurement. This was especially so when the method was applied to a large system using thermography. Furthermore, moving the large hoods was unsafe, and inconvenient for practical use. To solve these problems, a capacitor discharge circuit was introduced to change the temperature of a single hood [4].

However, a problem remained. The method requires accurate values of the ambient radiation-temperature before and after the change, and it was for this reason that the hoods were introduced. However, the temperature distribution in the inside surface of the hood is not uniform, and thus the ambient radiation-temperature at the object surface covered by the hood cannot be determined accurately.

In this paper, a new system is introduced where the effective ambient temperature can be determined accurately by simple equations.

II. METHODOLOGY

Theory

If the apparent reading of a black-body-calibrated radiometer (or infrared camera) is T_r, the radiation from the surface of the object contains emission from the object, and reflection from the surface as

$$W(T_r) = E_p\, W(T_s) + (1- E_p)W(T_a) \tag{1}$$

where $W(T)$, T_s, E_p, and T_a are the Planck radiation formula integrated through the sensitivity range of the detector, the true temperature, the emissivity of the object, and the ambient radiation-temperature, respectively.

When the ambient radiation-temperature is changed quickly from T_{aL} to T_{aH}, so that the surface temperature T_s of the object might be assumed to be unchanged, the outputs $W(T_{rL})$ and $W(T_{aH})$ of a radiometer, before and immediately after that change, are expressed as

$$W(T_{rL}) = E_p\, W(T_s) + (1- E_p)W(T_{aL}) \tag{2}$$
$$W(T_{rH}) = E_p\, W(T_s) + (1- E_p)W(T_{aH}) \tag{3}$$

If the ambient radiation-temperatures (T_{aL} and T_{aH}) are known, E_p and T_s can be obtained by solving these simultaneous equations.

Two sets of reference objects are introduced in order to calculate T_{aL} and T_{aH}. Each set contains two or more surface regions with the same temperature but different emissivities. The temperatures of the two sets should be different, so that the simultaneous equations (2) and (3) for the two objects having two different regions, provide eight simultaneous equations. This set of equations contains eight unknown variables (four values of emissivities, for the two values of the temperatures of the objects, T_{aL} and T_{aH}). Thus, the simultaneous equations can be solved and the T_{aH}, T_{aL} are obtained.

Then the true temperature and emissivity of any object in the field of view of the infrared (IR) camera can be obtained using (2) and (3).

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Estimation of Ambient Radiation Temperature for Emissivity-Corrected Thermography	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Institute of Biomaterials and Bioengineering Tokyo Medical and Dental University Tokyo, Japan	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
3

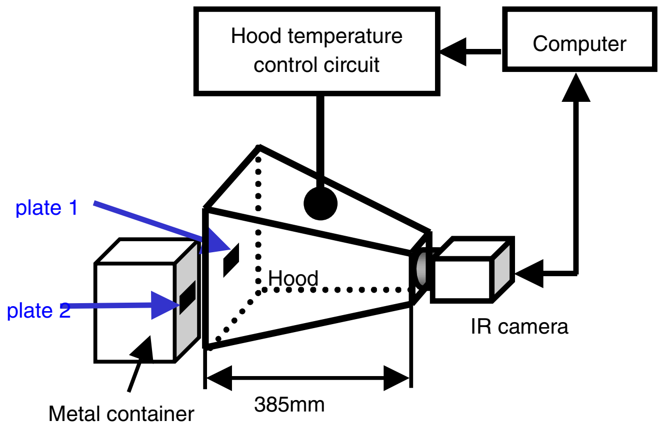

Fig. 1. A schematic diagram of the experimental set up. The hood temperature was controlled by the control circuit (HTCC) that consisted of a charge-discharge unit and temperature-holding unit. Both the IR camera and HTCC were controlled by a personal computer (PC) that also saved and processed the data from the IR camera. The opening of the hood is 270 mm square.

Experiment 1

This theory was checked using the following instruments (Fig. 1). The equipment to change the ambient radiation-temperature was similar to that used by Saito et al. [4], where the object was covered by a hood. An IR camera was set at the smaller opening of the hood. This Radiance 1t camera, manufactured by Amber Co., USA, had an InSb CCD detector with a wave-length sensitivity range of 3000–5000 nm, a temperature resolution of 0.002 K, and a maximum sampling frequency of 50 Hz. The temperature of the hood was increased abruptly by the discharge of a large capacitor (capacitance 0.12 F and voltage 500 V), and the temperature of the hood increased about 20 K within 0.2 s after the discharge. Therefore, the temperatures of the objects in front of the hood should not change significantly before and just after the change in the hood temperature. Sequential thermograms taken at intervals of 0.05 s were captured and saved with a personal computer. The thermograms just before and immediately after the capacitor discharge were used in the computation.

Two reference plates, having different temperatures, were made from copper. Each was coated with paints having different emissivity (ca. 0.84, 0.56, 0.46 and 0.18). These were set in front of the larger hood opening. One plate was attached to a metal container filled with warm water and the other was kept at room temperature. The temperature of the water was measured with a quartz thermometer (DMT-600, Tokyo Denpa Co.), against which the IR camera was calibrated.

The above-mentioned eight simultaneous equations were constructed from four pixels of the thermogram. The ambient radiation-temperatures (*Ta1* and *Ta2*) before and after the raising of the hood temperature were obtained from the simultaneous equations. Then the emissivity-corrected temperatures of the other pixels of the plate attached to the metal container were calculated, and compared with the output of the quartz thermometer.

Experiment 2

This method was also applied to human skin. Three reference plates were used in this experiment. A plate was attached to the inner forearm of a young male volunteer with adhesive tape. Each of the other plates was attached to a Peltier element. One plate was kept at room temperature, and the other was warmed to about 32 ^{o}C.

The procedure was the same as that used in experiment 1. Uncorrected thermograms were obtained at ambient temperatures before and just after the change. The ambient temperatures before (T_{aL}) and after (T_{aH}) the change were then calculated by applying the equations to the data over the area of the reference plates. Finally, these temperatures were used in conjunction with (2) and (3) to calculate the emissivity- corrected temperature and emissivity at the location of each pixel. The resulting images are shown in Fig. 3.

III. Results

Experiment 1

Fig. 2 shows the frequency distribution of the temperature of each pixel of the reference plate on the metal container. Although the temperature of each pixel of the plate on the metal container should be identical to the temperature of the water (vertical dotted line), the apparent temperature (Tr: output of the IR camera) was different over the regions with different paints (Fig. 2a). On the other hand, the emissivity-corrected temperature of each pixel was almost identical with the temperature indicated by the quartz thermometer (Fig. 2b). When the ambient temperature was estimated according to the value of the radiometer, as in the

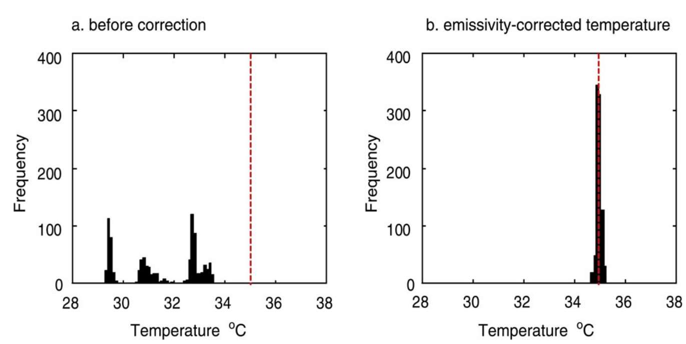

Fig. 2 Frequency distribution of the temperature of each pixel on the copper plate attached to the metal container. a: Temperature before correction (*Tr*) (i.e., output of the IR camera when the emissivity was set as 1). b: Temperature after correction (*Ts*) calculated with the Ta_1 and Ta_2 obtained from the simultaneous equations. The dotted line indicates the temperature measured with a quartz thermometer (34.95C).

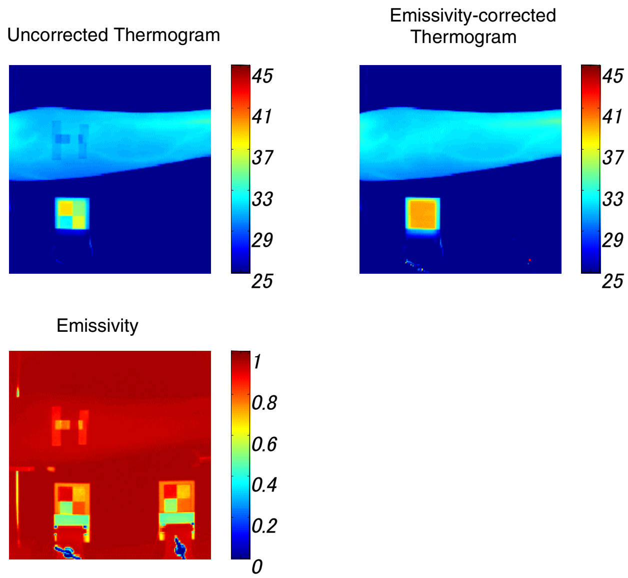

Fig. 3. Images of a: uncorrected thermogram, b: emissivity-corrected thermogram and c: emissivity of the inner forearm.

previous systems, the corrected values still varied (Okada, unpublished MS thesis).

Since each reference plate was painted with four different paints and each area contained more than 100 pixels, the number of combinations of pixels for the simultaneous equations is quite numerous. We compared the results of different combinations and obtained similar results as shown in Fig. 2.

Experiment 2

A typical result is shown in Fig. 3. Although the apparent temperatures of the reference plate were different in the regions with different paints, the emissivity-corrected temperatures were the same. Furthermore, the emissivity-corrected temperature of the plate attached to the skin was almost the same as that of the skin around the plate.

We used three reference plates in this experiment, and could calculate the ambient radiation-temperature using any two of the three reference plates. The results were almost identical.

IV. Discussion

The result of experiment 1 shows that the correct temperature of the object can be calculated using our method. It is strongly suggested that the ambient radiation-temperature before and after the change, was correctly obtained by solving the simultaneous equations introduced above. The result of experiment 1 also supported this. Furthermore, the result of experiment 2 suggests that the location of the reference plates does not affect the result. These results indicate that the ambient radiation-temperature can be obtained by solving the equations introduced in this study, and that this method of estimating ambient radiation-temperature can be applied to this system even if there is some non-uniformity in the temperature distribution in the hood.

It was difficult to change and/or keep the temperature of the inner surface of the hood uniform, even in the two-hood switching system. Therefore, this new method enables us to make the measurement system much simpler.

V. Conclusion

A new method has been introduced for a temperature and emissivity measurement system by changing ambient radiation-temperature abruptly. By introducing two reference plates coated with paints of different emissivities, this method has enabled us to obtain ambient radiation-temperatures by solving simultaneous equations, and eliminates the use of the hood used in the previous study.

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